A peer-reviewed open-access journal
NeoBiota
Advancing research on alien species and biological invasions

NeoBiota 104: 381–392 (2025)
DOI: 10.3897/neobiota.104.174530

Research Article

Children as frontline detectors: School-based programs can enhance early monitoring of *Vespa velutina*

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Abstract

The yellow-legged hornet (*Vespa velutina*) is an invasive predator that poses a significant threat to native biodiversity and apiculture in Europe. Early detection and rapid response are crucial to prevent its establishment and further spread. In this study, we tested the potential of using elementary school pupils as active contributors to *V. velutina* surveillance through a targeted educational program. A total of 358 pupils (aged 10–11 years) participated in a program that included information on *V. velutina* biology, its ecological and economic impacts, and key identification features, supported by practical demonstrations using real specimens.

Knowledge of fundamentals of *V. velutina* biology and identification skills were assessed using pre-tests, post-tests one week after the program, and follow-up tests after 2–3 months. The results showed a significant improvement in both knowledge scores and identification accuracy, with knowledge retention confirmed several months later. In a practical verification experiment six months after the program, dead *V. velutina* individuals were placed in classrooms on the windowsill; and their presence was successfully reported in 64.3% of the cases. Control of the verification experiment, by placing dead *V. crabro* individuals into the classrooms, resulted in no false reports of invasive species.

These findings demonstrate that educational programs can be a simple, cost-effective tool for increasing public engagement in invasive species monitoring, significantly improving early detection capacity. Implementing such programs, particularly in regions at risk of invasion, could greatly enhance management strategies and reduce socio-economic and ecological impacts.

Key words: Apiary, beekeeping, citizen science, early detection, environmental education, invasive species management

OPEN ACCESS

Academic editor: Mark Hoddle
Received: 10 October 2025
Accepted: 8 December 2025
Published: 19 December 2025

Citation: Ditrich T, Lustová Š (2025) Children as frontline detectors: School-based programs can enhance early monitoring of *Vespa velutina*. NeoBiota 104: 381–392. https://doi.org/10.3897/neobiota.104.174530

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Introduction

The yellow-legged hornet (*Vespa velutina*) (Hymenoptera, Vespidae) is one of the most significant emerging threats to both European and global ecosystems and apiculture (Lioy et al. 2022). *Vespa velutina* is a major predator of pollinators and decomposers (Rojas-Nossa and Calviño-Cancela 2020; Herrera et al. 2025; Pedersen et al. 2025); it causes substantial damage to agriculture by reducing numbers of pollinators and by feeding on fruit (Nave et al. 2024), and this pest poses a severe threat to beekeeping. *Vespa velutina* actively hunts honeybees, locates apiaries, and can decimate up to 80% of hives in areas where it is established (Laurino et al. 2020). Its presence therefore represents a significant threat to local beekeeping

operations (Diéguez-Antón et al. 2025) which may have far-reaching socio-economic consequences (Barbet-Massin et al. 2020; Lioy et al. 2022).

The spread of the yellow-legged hornet from its native range in Asia to Europe began with the introduction of possibly a single queen from China to France in 2004 (Arca et al. 2014), followed by the colonization of almost the entirety of France by 2017 (Robinet et al. 2018). From France, *V. velutina* invaded Spain in 2010 (López et al. 2011), Portugal in 2011 (Grosso-Silva and Maia 2012), Italy in 2013 (Porporato et al. 2014), Germany in 2014 (Witt 2015), and the United Kingdom in 2016 (Budge et al. 2017). By 2020, individuals were reported in Switzerland, the Netherlands, and Ireland (Lioy et al. 2022). More recently, nests were found in 2023 in the Czech Republic (Walter et al. 2024), Hungary (Márta and Vas 2023), and in Slovakia in 2024 (Kolics et al. 2025; Purkart et al. 2025). A single individual without an established colony has been reported in Austria (Schorkopf et al. 2024). An updated map of nest locations in Europe is provided by INPN (2018). Meanwhile, the invasion into North America has started, as the first colonies were found near Savannah (Georgia, USA) in 2023 (Hoebeke et al. 2024), and in New Zealand, *V. velutina* queens were reported in November 2025 (RNZ 2025).

It is clear that the invasion of the *V. velutina* across Europe has not ceased, although lower temperatures in the northeast direction from the first colonization may slow its expansion (Requier et al. 2025). However, with rising temperatures across Europe, further spread is highly probable (Nie et al. 2024; Zhang et al. 2024). Therefore, continuous efforts to stop, or at least slow the invasion, are urgently needed. Several approaches have been proposed for this purpose. Generally, the management of *V. velutina* invasions operates on three levels: prevention, early detection, and eradication (Lioy et al. 2022), with various degrees of ecological and biological control assisting management efforts (Turchi and Derijard 2018; Laurino et al. 2020, Lester 2025). However, many of the proposed control methods have proven ineffective (Thiery and Monceau 2024). Successful eradications have been achieved in the United Kingdom (Jones et al. 2020) and Mallorca (Spain) (Leza et al. 2021) and successful eradication in newly colonized areas requires rapid detection and elimination of all nests (Keeling et al. 2017).

New and innovative early detection methods for *V. velutina* are emerging, including artificial intelligence (AI)-based tools (María-Luisa and Jesús-Ángel 2024; O'Shea-Wheller et al. 2024) and automated sound detection (Hall et al. 2025). Nevertheless, both examples of successful eradication, and general management strategies, emphasize the critical role of public engagement and citizen science in the initial detection of *V. velutina* individuals (Warren et al. 2025). The general concept of involving the public in monitoring consists of citizens reporting hornet sightings to experts, who then locate and destroy nests using various methods (see Laurino et al. 2020 for a review). Public involvement significantly expands the monitored area; however, public assistance has certain limitations. Primarily, there is relatively low accuracy in the correct identification of *V. velutina*. For example, Wade et al. (2025) reported only 16.8% correct identifications in Guernsey over three years. Rome et al. (2011) estimated public identification accuracy at approximately 30%. Servia et al. (2020) reported a 33% correct identification rate among visitors at a bee festival (mostly motivated and experienced public), and Leza et al. (2021) found only 8% accuracy in public reports from Mallorca. Notably, in this successful eradication effort in Mallorca, a specially developed reporting app was downloaded by only 3,685 people (i.e., < 0.5% of more than 800,000 of inhabitants at the time of the project).

We identified two main limiting factors in public involvement in *V. velutina* monitoring and early detection: (a) only a small proportion of the public is aware of the danger posed by this invasive species and is therefore willing to participate in citizen science initiatives; and (b) the low level of correct species identification by the public, which complicates subsequent nest search and eradication efforts.

For these reasons, we tested whether elementary school pupils could be effectively educated on how to deal with monitoring, detection, and correct species identification. Children represent a significant portion of the population, and with appropriate training, they can develop strong observational skills, making them potentially valuable contributors to yellow-legged hornet detection efforts. If pupils can be taught to reliably identify *V. velutina* and know how to report sightings, incorporating these types of programs into schools could substantially contribute to slowing or halting the spread of this pest.

Methods

In this study, an educational program was developed for 5th-grade elementary school pupils (aged 10–11 years), aimed at introducing children to the existence and risks of *V. velutina* (particularly in relation to beekeeping; a detailed description of the educational program is provided in Suppl. material 1). An important part of the program was a practical demonstration of *V. velutina*, with an emphasis on its identification characteristics.

To maintain the clarity of the real specimens while avoiding potential discomfort (fear or disgust) among pupils due to direct contact with insects, individuals of *V. velutina* embedded in transparent resin were used. Similarly prepared specimens of other hymenopteran species that are commonly misidentified by the public as *V. velutina* (such as *Vespula vulgaris*, *Vespula germanica*, and *Vespa crabro*; Wade et al. 2025) were also included. The use of real *V. velutina* specimens helped avoid misidentification errors that may occur when using images instead of physical specimens.

As part of the program, a leaflet containing the telephone number of the second author was displayed, encouraging participants to report any potential sightings of *V. velutina* (due to the ban of mobile phones at some schools, the pupils were encouraged to report any potential sightings to their teacher who then contacted the authors). The educational program was conducted in a total of 20 classes across České Budějovice (South Bohemia, Czech Republic) between October and December 2024. Even though *V. velutina* has not yet been found within the city of České Budějovice, there is a high probability of future occurrence (Walter et al. 2024).

Immediately before the start of the program, pupils completed a short pre-test focused on basic knowledge of the existence of the *V. velutina*, its relevance to humans, and its identification (the test and scoring is provided in Suppl. material 2). The same test was administered one week after the educational program, and again two to three months later (January–February 2025), which enabled the assessment of knowledge retention over time. Such information recall can be considered as a long-term memory (Rattat and Droit-Volet 2007). Overall test scores and the accuracy of *V. velutina* identification based on images (expressed as a proportion of correct identifications per class) were analysed using repeated-measures ANOVA (pre-test, post-test 1, and post-test 2). Analyses were conducted using Statistica 14 (TIBCO 2020) with the significance level set at $\alpha = 0.05$.

A key part of evaluating the program's effectiveness took place in June 2025, when a dead specimen of a *V. velutina* was placed on the classroom windowsill in the participating schools. One week before this part of the study, the teachers and other school workers were informed about the plan, and in cases where consent was obtained (14 out of 20 classes/teachers agreed), the school staff were instructed accordingly (mainly to avoid alerting pupils to the specimen or removing it during cleaning). The dead individual was placed and left on the windowsill for five consecutive days; if it was not reported in the class during that time, it was removed. Early June was chosen for specimen deployment because of the sufficiently high temperatures and plausible seasonal activity pattern of *V. velutina*. As information leaflets were still present in the classrooms, the pupils could report the finding of *V. velutina* at the telephone number displayed on the leaflet or report it to the teacher. Three months later, in September 2025, a control of determination assessment (possible occurrence of false alerts) was carried out – a dead individual of a native vespid, *Vespa crabro*, was placed on the classroom windowsill in the participating schools (all but one participating class agreed with the placement of this non-invasive dead specimen). All other arrangements were identical to the June trial with *V. velutina*, the information leaflet was still present and pupils could again report any suspected presence of *V. velutina* or any uncertainty regarding the identification of the provided specimen. As summer holidays spanned the period between the practical assessments of the invasive (*V. velutina*) and native (*V. crabro*) species, some classes changed between these two events. Most classes remained unchanged (90% of pupils unchanged from the previous grade), 80–90% of pupils were unchanged in two classes and 70–80% in the remaining three classes.

By this approach we tested the long-term effect of the educational program, specifically, whether pupils could still recall the diagnostic features of *V. velutina*, recognise its potential risk, and report its presence after more than six months. The appearance of the specimen on the windowsill mimicked the actual occurrence of *V. velutina* observed in Austria in 2024 (Schorkopf et al. 2024). We also tested if trained children would be able to avoid false alerts (mistaking native *V. crabro* for invasive *V. velutina*). All *V. velutina* specimens (both for embedding in resin and for evaluating program effectiveness) were provided by Jan Walter (West Bohemian Museum in Pilsen). These individuals (all our specimens were workers) originated from the first *V. velutina* nest discovered in the Czech Republic near Pilsen (Walter et al. 2024). The research methods used in this study were approved by The Ethics Committee of the Faculty of Education of the University of South Bohemia, approval No. EK060/2025.

Results

A total of 358 pupils participated in the educational program, 285 (80%) of whom were present on both post-tests. Analysis of the knowledge test scores revealed a highly significant improvement in the mean number of points achieved ($F_{2,568} = 420.02$; $p < 0.001$) as well as in identification accuracy ($F_{2,34} = 134.71$; $p < 0.001$) (Fig. 1).

In the next phase of the study, when a dead specimen of *V. velutina* was placed in the classroom, its presence was reported immediately (on the same day) in five classes. The following day, it was reported in an additional four classes (in one of these, a pupil noticed the specimen on the first day, took it home for careful examination, and reported it to the teacher the next day after confirming the

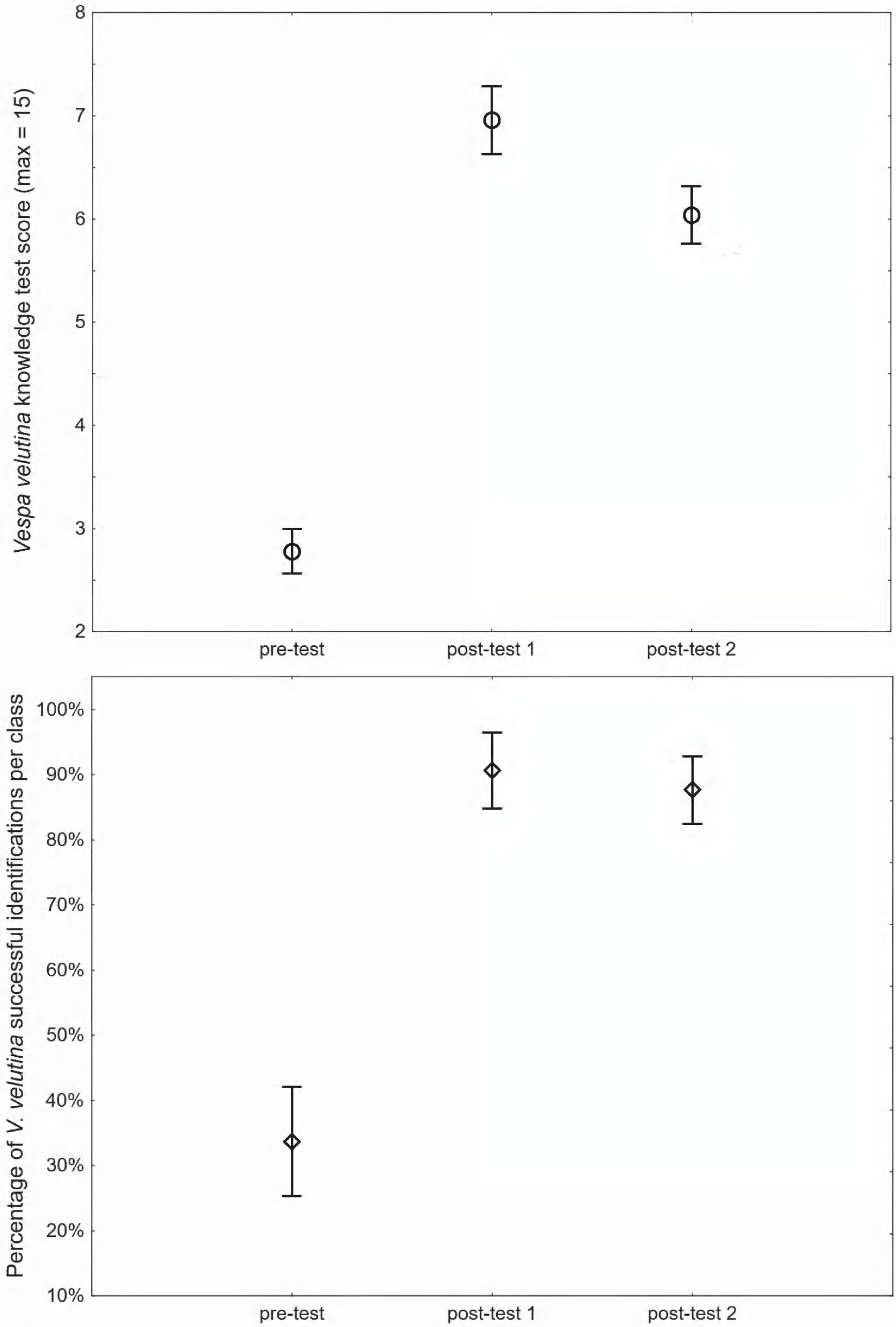

Figure 1. Results of the knowledge test (A) and identification accuracy (B) before the educational program (pre-test), one week after the program (post-test 1), and two to three months after the program (post-test 2). The increase was highly significant in both cases (both $p < 0.001$). Vertical bars denote 0.95 confidence interval.

identification). *V. velutina* was not reported in the remaining classes. Overall, the *V. velutina* specimen was reported in 9 out of 14 (64.3%) participating classes during the five-day observation period.

Three months later, in the control part of the experiment (false alerts assessment), we received no false reports of *V. velutina* as no students mistook *V. crabro* as *V. velutina*. This absence of false reports held for both the classes that had previously participated in the *V. velutina* phase (14 classes) and for the additional classes where we were not allowed to conduct the earlier phase and for which the *V. crabro* specimen represented their first exposure to an experimental dead wasp (5 classes).

Discussion

The results clearly demonstrate that elementary school pupils could become an effective part of efforts to detect the spread of the *V. velutina*. Prior to the educational program, student knowledge of *V. velutina* was very limited; awareness of this species and its potential risks was observed only among children actively involved in beekeeping, either directly or through family members. The knowledge and identification skills acquired during the education program were long-lasting, suggesting that the intervention had a sustained impact on participants. There are several limitations to the current study, primarily because we were granted permission to carry out the *V. velutina* practical identification assessment (placement of the dead specimen on the windowsill) in only 14 classrooms. Our original design – placing *V. velutina* in half of the classrooms and the native *V. crabro* in the other half – would have resulted in very small sample sizes, and the outcomes might therefore not have been statistically significant due to low statistical power. The control part of the experiment (false-alert assessment) was therefore conducted after the summer break, in the same classes (but in a different grade). This may have influenced the results, as the composition of each class had changed slightly, and children returning from the summer break are still adjusting to new subjects, teachers, and routines, potentially altering their cognitive and attentional states. However, a similar argument applies to the first phase of the practical identification experiment conducted in June. Children are typically distracted at the end of the school year, looking forward to the summer break and participating in class trips and other activities. Because the first phase took place in June (6–7 months after the educational program and 4–5 months after the second post-test), when attention to invasive hornets had already declined, we consider it comparable to the second phase in September (a further 3 months later). Another limitation of this study is identification of dead specimens on the windowsill, and not testing the ability of students to identify flying *V. velutina* or individuals feeding on fruit or flowers. We aimed to simulate a realistic situation (avoiding use of images and videos), which restricted us to using dead *V. velutina* specimens (and even if live individuals had been available, they could not have been used for safety reasons). However, the presence of a dead individual on a windowsill used in this training program reflects the first recorded observation of *V. velutina* in Austria, where it was found on a hospital window (Schorkopf et al. 2024). It is reasonable to assume that if a *V. velutina* individual were trapped indoors, in a classroom for example, for several days (e.g., over a weekend), it would likely end up as a dead specimen on the windowsill, similar to what was recorded in Austria.

Educational programs on invasive species can be implemented in schools relatively easily and at low cost, enabling the rapid creation of hundreds of informed "assistants" who are aware of *V. velutina*, understand its negative impacts, and are capable of recognising and reporting this pest. Thus, the number of people engaged in monitoring this invasive species could dramatically increase, addressing the current shortage of citizen scientists involved in such surveillance efforts (Leza et al. 2021; Wade et al. 2025). Furthermore, this approach can significantly reduce misidentifications, which is a major limitation in the use of public reporting data (Rome et al. 2011; Servia et al. 2020; Leza et al. 2021; Wade et al. 2025). Lack of trained voluntary detectors, like students for example, increases the need for expert verification and raises the overall costs of management and eradication efforts. Repeating these types of education programs yearly, possibly as part of a science curriculum on invasive species, with both naïve and experienced children, could greatly increase the number of involved children and thus increasing also the probability of accurate reports on the invasive pest of concern, which in this case is an invasive insect, *V. velutina*. The number of children involved in such educational programs is important – knowledge and identification skills will not last forever in all children, but the strength of our approach lies in numbers – children can be easily educated in large quantities, and even if only a small proportion of them are vigilant for a long time, the training program may potentially increase the number of reliable reports significantly. Another big advantage of such an approach is the involvement of children in a real and important task. Children who feel a sense of responsibility acquire greatly increased levels of awareness and motivation (Hart 1997; Mackey 2012).

As existing preventive measures to slow the spread of *V. velutina* have measurable but limited effects (Hassall et al. 2025), widespread implementation of similar educational programs in schools is highly desirable, especially in regions where invasions are in their early stages and where rapid detection and elimination of newly established nests are crucial. These regions include most Central European countries (such as the Czech Republic, Austria, Slovakia, and Hungary), as well as other European areas where *V. velutina* has not yet been reported, but where its spread cannot be excluded or is even expected (nearly all European regions; see Robinet et al. 2018). The use of training insects embedded in resin is advantageous as it can reduce the discomfort of participants who may be nervous handling insects. However, handling real specimens may not always be necessary, as high quality images and informative leaflets were shown to be effective training tools for monitoring *V. crabro* in Sardinia (Pusceddu et al. 2019).

Beyond Europe, educational programs should also be urgently introduced in countries such as the U.S. or New Zealand, where the establishment and spread of *V. velutina* has already begun (Hoebeke et al. 2024; RNZ 2025), and Mexico, where invasion is anticipated (Ruiz-Utrilla et al. 2024). Particularly in these areas, educational content could also include information on *Vespa mandarinia*, the Japanese giant hornet, another dangerous invasive vespid species that is starting to spread in these regions (Ruiz-Utrilla et al. 2024; Taylor et al. 2024).

By adopting this simple and cost-effective measure, it may be possible to prevent irreversible biodiversity changes and significant global socio-economic damage that result from invasive species like *V. velutina*. The spread of invasive hornet species threatening apiculture can be expected to continue and will adversely affect large

parts of the world (Zhang et al. 2024). This reality makes proactive educational strategies, like the one detailed here, a highly relevant tool for early detection, monitoring, and mitigation.

Acknowledgements

We would like to thank all teachers and school workers who allowed us to carry out the research. We are grateful to Jan Walter (West Bohemian Museum in Pilsen) for providing specimens of *V. velutina*.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

The research methods used in this study were approved by The Ethics Committee of the Faculty of Education of the University of South Bohemia, approval No. EK060/2025.

Use of AI

No use of AI was reported.

Funding

The research was funded by the project of the USB Grant Agency n. GAJU 042/2022/S and a project of the City of České Budějovice No. OŽP-2024-2-06.

Author contributions

Tomáš Ditrich made the research conception and design. Educational programs were carried out by Štěpánka Lustová, who also evaluated the tests and made the demonstration kit for every class. Both authors carried out the assessment of native and invasive species determination; both authors analyzed the data; the first draft of the manuscript was written by Tomáš Ditrich, Štěpánka Lustová commented on the manuscript. Both authors have read and approved the final manuscript.

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Data availability

The structure of an educational program is provided in Suppl. material 1; test and scoring is provided in Suppl. material 2; data for analyses are available at https://doi.org/10.48700/datst.1v7c8-h4398.

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Supplementary material 1

Structure of the educational program with information on Vespa velutina

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Data type: .docx

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Supplementary material 2

Short test focused on basic knowledge of the existence of Vespa velutina, its relevance to humans, and its identification

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Data type: .docx

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